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# NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

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NAVAL SHIP RESEARCH AND DEVELOPMENT LABORATORY  
Annapolis, Maryland 21402

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## A PROPOSED SHIPBOARD CONTINUOUS OIL POLLUTION CONTROL PROCESS FOR BILGE WATER

By  
Dr. Tsi Shan Yu

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A proposed Shipboard Continuous Oil Pollution Control Process  
for Bilge Water

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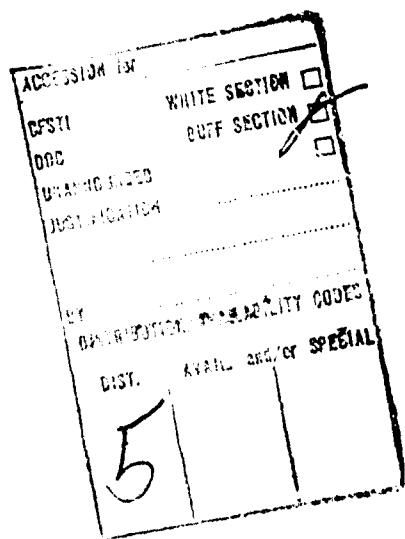
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October 1969

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## ABSTRACT

A continuous gravitational process to separate oil pollutant from ships' bilge water using simple and compact equipment is proposed. The principle of the process is discussed. For an oil-water mixture of known concentration and density, the location of the interface inside the separator for different flow rates can be predicted. Laboratory experiments will be conducted to test the proposed process prior to consideration of further tests aboard ship.

## ADMINISTRATIVE INFORMATION

The NSRDC Program Summary, "Ballast Water-Fuel Oil Removal System (U)," Task Area SF 35 433 006, Task 10183, was amended in November 1968 to include the treatment of bilge water. The title in the Program Summary has been changed to "Shipboard Bilge And Ballast Water Oil Pollution Control System (U)" under the same task area and Task 13216.

This report of proposed process to treat bilge water is a part of Phase I (c), "Setting Goals and Proposing Technical Approach", leading toward Phase II, "Development and Testing of a Prototype System." The work is being performed under Work Unit 1-821-156-A.

## ADMINISTRATIVE REFERENCES

- (a) OPNAVINST 3120.21A, OP-332E, Ser 1879P33 of 3 Aug 1968
- (b) NAVSEC ltr 6154H:AEC:mw 9480-1, Ser 284 of 21 Mar 1969

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INTRODUCTION

Oily bilge water must be pumped overboard to prevent flooding the ship and damaging the ship's machinery. To prevent pollution of the sea the oil must be removed from the bilge water prior to discharge. The development of an effective system to accomplish this is one part of the Bilge and Ballast Water Oil Pollution Control Program. A state-of-the-art search for equipment and processes to separate oil from water has been completed.(1)

An awareness of recent developments also is desirable. On the basis of the information that has now been assembled, a compact gravitational process has been conceived that is considered potentially feasible for satisfactory treatment of water aboard ship. This process does not rely on chemicals but allows for the use of demulsifier when a stable emulsion occurs in the bilge water. This report describes and discusses the proposed process.

BACKGROUND

One of the sources of oil pollution attributable to ships is the discharge of bilge water. This water contains oils from drains and leaks in the lubricating-, hydraulic-, and fuel-oil systems as well as from the water systems aboard ship. This oily water mixture is required to be pumped overboard to prevent flooding of the ship and damage to the ship's machinery. The pumping of bilge water is therefore necessary when the amount reaches a certain level inside a ship whether the ship is in harbor or on the high sea.

OPNAVINST 3120.21A (reference (a)) prohibits naval ships of the United States from discharging water having more than 100 ppm\* of persistent oils (crude, fuel, heavy diesel, and lubricating) into the navigable and coastal waters of the United States. Furthermore, the resolutions of the 1962 International Conference on the Prevention of Oil Pollution on the Seas called by the Intergovernmental Maritime Consultative Organization (IMCO) requested that

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(1) Superscripts in parentheses refer to similarly numbered entries in Appendix A.

\*Abbreviations used in this text are from the GPO Style Manual, 1967, unless otherwise noted.

naval ships of the signatory countries observe the limitation and the prohibited zones set forth. A proposal of limiting oil content in the discharging water from ships on high seas to 60 liters per nautical mile has been made to the IMO, and a longer range aim of allowing no oil in ships discharging water has been discussed. At present United States naval ships do not have a reliable system for the removal of the oil in their bilge water before discharging it.

In harbors and depots naval ships may rely on barges or doughnuts to receive their oily bilge water. (A doughnut is a floating cylinder open at both ends. It allows the discharged water to be displaced through the bottom opening and is intended to retain the discharged oil inside the cylinder.) However, barges and doughnuts are not always available when a ship has to discharge its bilge water. Only very few ports or dock areas have waste oil piping systems to accept and transfer the oily bilge water from ships to a nearby point for clarification treatment.

While new and large commercial ships have some type of oily water separator on board to treat their bilge water, naval ships do not have such facilities. To abide by the national and international requirements of oil pollution abatement, naval ships are in need of such shipboard capability. Because of the existing space and weight limitations and the commitment of personnel, any separator to be used on naval ships would have to be compact and easy to operate.

The amount of oil in the bilge water and the rate at which the bilge water is being accumulated in a ship vary from ship to ship depending on the ship's condition and personnel.

Some bilge water samples received from USA GAINARD (DD 706) were found to have oil contents varying from 8 to 9000 ppm.<sup>(2)</sup> These samples were collected at different dates. This large range of oil content indicates that the bilge water samples could be collected under various pumping conditions. As the interface of oil and water approaches the discharging point in a container, the oil content in the discharging water is expected to increase. This has been confirmed in another investigation.<sup>(3)</sup> It has also been indicated<sup>(4)</sup> that different types of pumps at different speeds will cause oil to disintegrate into droplets of various sizes. Oil drops of 0.01 inch in diameter are difficult to separate from oil-water mixtures. An estimated bilge water-stripping rate of 10 gpm has been suggested as a reasonable rate for equipment design considerations (reference (b)).

#### PREVIOUS WORK

A state-of-the-art search<sup>(1)</sup> for shipboard oil pollution control systems indicated that:

- Separation techniques such as evaporation, distillation, crystallization, or freezing are not desirable because of the need for heavy equipment and large supplies of heat or electrical power.
- Separation methods using hydrocyclone chromatography, sonic, electric/magnetic, and biological techniques are still not suitable

shipboard use because of their small flow rates or inefficiency. Further developments in these areas are still needed.

- Centrifuging is not considered to be economical since most of the material centrifuged is to be discarded overboard.
- Coalescing/filtering techniques require different selective adsorbents for different materials to be separated. Materials containing surfactants such as Navy standard fuel oil (NSFO) have been found to render the presently known adsorbents ineffective as separating media after a short period of use.
- Flotation appears useful as an auxiliary process.
- Chemical treatment is not a preferred method because (1) it requires skilled operators to administer the chemicals; (2) it can also produce another pollutant; and (3) it may require special materials in equipment construction. A limited use of chemicals to assist in breaking tight water-oil emulsions, however, is not objectionable.
- Settling by gravitation is the preferred method because of its potential low cost and simplicity. Although settling may be too slow for handling large volumes of ballast water, it will probably be suitable for handling the smaller volumes of bilge water at a flow rate of 10 gpm.

#### PROPOSED PROCESS

Separation of oil from water is not a simple process. While oil and water are immiscible in general, under a variety of conditions oil will form emulsions with water, and it thus becomes dispersed as a mixture of small drops in the water. The complete separation of oil and water from emulsions is difficult. With respect to large scale separations in general, manufacturers have spent millions of dollars to produce pure materials, and most of the products produced are still in the 98%-99% purity range (or contain 1%-2% impurities). The new process proposes to separate the major amount of oil present from the bulk of the bilge water by gravitational settling and to re-process the remainder with fresh accumulations of bilge water. Gravitational settling is used to take advantage of the difference in oil and water densities. The theory of its application and the equipment to be used are described below.

#### THEORY

The key element in the proposed process is a continuous gravitational liquid separator, Figure 1. The factors of density, oil concentration, and flow rates governing the separation of a mixture of oil and water admitted into the separator are derived as follows. It is assumed that the oil-water mixture entering the separator will not be emulsified. Let the symbols listed represent various factors as defined below.

$\rho_h$	density of the heavier liquid water
$\rho_l$	density of the lighter liquid oil
$\rho_m$	density of the oil-water mixture entering the separator

$z_s$	total liquid height inside the separator
$A_s$	cross-sectional area of the separator
$z_{h1}$	height of the heavier liquid layer inside the separator
$z_{\ell 1}$	height of the lighter liquid layer inside the separator
$z_{\ell 2}$	height of the discharge of the heavier liquid
$A_m$	cross-sectional area of the pipe for the oil-water mixture to enter the separator
$U_m$	linear flow velocity of the oil-water mixture
$A_h$	cross-sectional area of the pipe for the heavier liquid discharge (underflow)
$U_h$	linear flow velocity of the heavier liquid discharge (underflow)
$A_{\ell}$	cross-sectional area of the pipe for the lighter liquid discharge (overflow).
$U_{\ell}$	linear flow velocity of the lighter liquid discharge (overflow).
$R$	ratio of the fluid densities ( $\rho_{\ell} / \rho_h$ )
$C_{\ell}$	fraction of the lighter fluid in the entering oil-water mixture
$C_h$	fraction of the heavier fluid in the entering oil-water mixture
$V_m$	volumetric flow rate of the oil-water mixture entering the separator
$V_h$	volumetric flow rate of the heavier fluid (water) leaving the separator
$V_{\ell}$	volumetric flow rate of the lighter fluid (oil) leaving the separator.
$\theta$	residence time = $z_s A_s / V_m$

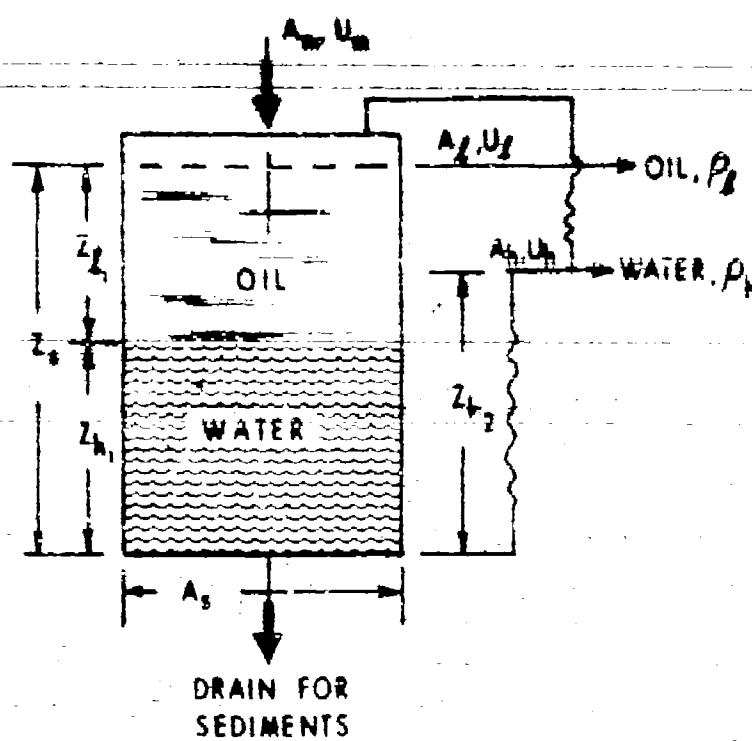


Figure 1  
Continuous Gravitational  
Liquid Separator

Based on the static pressure balance principle about the separator, an equation can be written

$$Z_{h2} \rho_h = Z_{f1} \rho_f + Z_{h1} \rho_h \quad \dots \dots (1)$$

or

$$Z_{h1} = Z_{h2} - Z_{f1} R \quad \dots \dots (2)$$

Since

$$Z_s = Z_{h1} + Z_{f1} \quad \dots \dots (3)$$

Equation (2) can now be written as

$$Z_{h1} = Z_{h2} - (Z_s - Z_{h1}) R \quad \dots \dots (4)$$

or

$$Z_{h1} = \frac{Z_{h2} - Z_s R}{1 - R} \quad \dots \dots (5)$$

A material balance relationship around the separator can also be written. Under this relationship, the masses flowing in and out of the separator must be balanced by the change inside. The mass balance equation is:

$$\rho_{m,1} A_m + \rho_{h,1} A_h + \rho_f V_f = \rho_{m,2} A_m + \rho_{h,2} A_h + \rho_f V_f \quad \dots \dots (6)$$

In terms of volumetric flow rates, Equation (6) becomes

$$\rho_m V_m - \rho_h V_h - \rho_f V_f = A_s \left( \rho_h \frac{dZ_{h1}}{d\theta} + \rho_f \frac{dZ_f}{d\theta} \right) \quad \dots \dots (7)$$

Since

$$dZ_{h1} = dZ_f \quad \dots \dots (8)$$

Equation (7) becomes

$$\rho_m V_m - \rho_h V_h - \rho_f V_f = A_s (\rho_h - \rho_f) \frac{dZ_{h1}}{d\theta} \quad \dots \dots (9)$$

Substituting  $Z_{h1}$  from Equation (5), Equation (9) becomes

$$\rho_m V_m - \rho_h V_h - \rho_f V_f = A_s (\rho_h - \rho_f) \frac{d}{d\theta} \left( \frac{Z_{h2} - Z_m}{1 - R} \right)$$

$$(\rho_m V_m - \rho_h V_h - \rho_f V_f) d\theta = \frac{A_s (\rho_h - \rho_f)}{1 - R} dZ_{h2} \quad \dots \dots (10)$$

As the effluent reaches  $Z_{h2}$  after residing in the separator, Equation (10) can then be integrated over the residence time,  $\theta = Z_m A_s / V_m$ , to obtain (flow in the opposite direction)

$$(\rho_m V_m - \rho_h V_h - \rho_f V_f) \frac{Z_m A_s}{V_m} = \frac{A_s}{1 - R} (\rho_h - \rho_f) Z_{h2} \quad \dots \dots (11)$$

Solving for  $Z_{h2}$ , with  $V_f = V_m - V_h$

$$Z_{h2} = \frac{\left[ \rho_m V_m - \rho_h V_h - \rho_f (V_m - V_h) \right] Z_m (R - 1)}{V_m (\rho_h - \rho_f)} \quad \dots \dots (12)$$

$$= \left[ \left( \frac{\rho_m}{\rho_h - \rho_f} \right) - \frac{V_h}{V_m} \right] Z_m (R - 1) \quad \dots \dots (12)$$

Assuming additive property for  $\rho_m$ ,

$$\rho_m = \rho_h (1 - C_f) + \rho_f C_f \quad \dots \dots (13)$$

Equation (13) becomes

$$z_{h_2} = \left[ \frac{\rho_h(1-C_f) + \rho_f C_f - \rho_f}{\rho_h - \rho_f} - \frac{v_h}{v_m} \right] z_s \quad (13)$$

$$= \left[ (1-C_f) - \frac{v_h}{v_m} \right] z_s \quad (13) \quad \dots \dots \quad (14)$$

Using this derived relationship for the separator to discharge water containing 100 ppm of oil or 0.01% oil in water, the amount of oil in the underflow discharge is:

$$\rho_f v_f = C_f (\rho_m v_m) = 0.0001 \rho_h v_h \quad \dots \dots \quad (15)$$

Using relations in Equations (12) and (13), Equation (15) becomes

$$\frac{v_h}{v_m} = \frac{1 - C_f [1 - C_f(1-R)]}{R - 0.0001} \quad \dots \dots \quad (16)$$

As 0.0001 is comparatively very small with R, it can be neglected, i.e.  $R = 0.0001 \sim R$ ; then Equation (16) becomes

$$\frac{v_h}{v_m} = \frac{1 - C_f + C_f^2 (1-R)}{R} \quad \dots \dots \quad (17)$$

Substitute this relation into Equation (14) and it becomes

$$z_{h_2} = \frac{(1-R)^2}{R} z_s (1 - C_f + C_f^2) \quad \dots \dots \quad (18)$$

Equation (18) predicts the height of the effluent discharging head. Here,  $C_f$  is the oil concentration of the influent stream. When this concentration is low, the term  $(1 - C_f + C_f^2)$  approaches 1, and Equation (18) can be approximated as

$$z_{h_2} \approx \frac{(1-R)^2}{R} z_s \quad \dots \dots \quad (19)$$

A plot of this equation for few values of R is shown as Figure 2.

The above derived relations do not indicate dependence on the size of the separator. The size of the separator depends on the residence time, which in turn, depends on the droplet size and densities of the two fluids involved. It may seem that the flow rates do not affect the operation from these derived equations, (5) and (18). In fact, the flow rates and the pipe sizes have effects on droplet sizes and the residence time required. When the pipes are small, the linear velocities of the fluids in them are high and thus high disturbances result. Thus, a longer residence time will be needed.

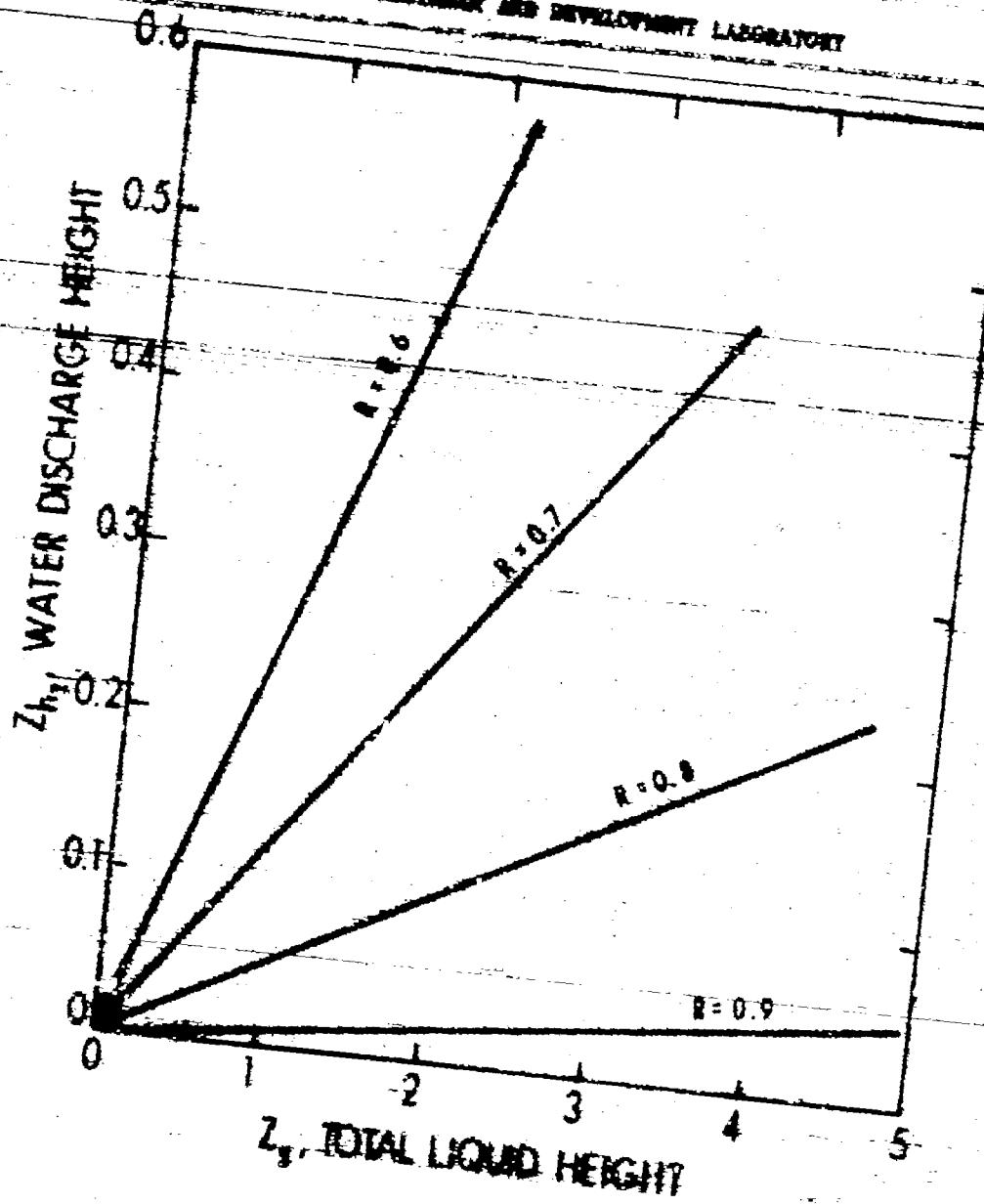


Figure 2  
Estimated Effluent Discharge Height

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As an illustration, the size of a cylindrical separator for influent rate of 10 gpm and for a residence time of 20 minutes will be

$$\text{Volume} = 10 \times 20 = 200 \text{ gallons or } 26.7 \text{ cu ft} = \frac{1}{3} \pi D^2 Z_g$$

For this capacity, the separator can have the dimension of the diameter and height as:

Diameter feet	Height feet
1	35.1
2	8.8
3	3.9

A proper choice of the dimensions would therefore depend on the available space or any equipment to go inside the separator.

#### EQUIPMENT

A flow diagram of the proposed process appears in Figure 3. The process is based on the continuous gravitational liquid separator preceded by a heated and baffled skimmer to break any tight emulsion and to skim off any floating oil. It is followed by a filter to retain any remaining oil in the underflow water from the separator. While the skimmer is for pretreating the oily water mixture, the filter is a safeguard.

#### Skimmer

The heated and baffled skimmer for pretreatment would have a larger capacity than the continuous gravitational liquid separator to take up recycled liquid for reprocess when needed. It can also act as a surge tank when there is a sudden increase in the amount of bilge water. This pretreatment operation may also be bypassed when there is no emulsion in the bilge water. It is also the place to add demulsifying agents when needed as an aid to the process. The intake of the bilge water will be close to the bottom so that any separated water layer will be removed from the bilge first. A screen filter is placed before the pump inlet to remove large solids that may be in the bilge water.

#### Separator

The separator can be a cylindrical tank of convenient dimension. It has an overflow exit for the lighter fluid, oil, near the top and a discharging exit for the heavier liquid, water, near the bottom. A flexible hose or pipe will be connected to this underflow exit so the discharging head may be adjusted if required. A tapered bottom is preferred for collecting any sediment that may be in the water.

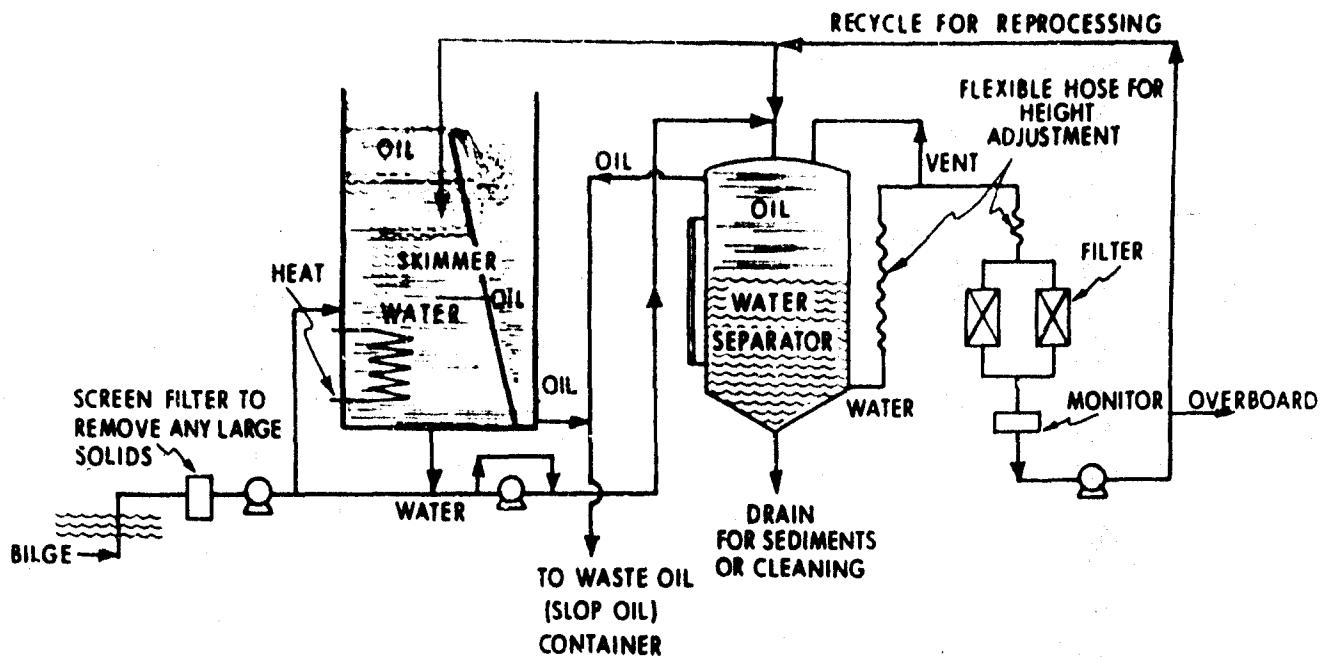


Figure 3  
Proposed Process

### Filter

The proposed process will also use a final oil-removal filter as a safeguard. The filter case will consist of two transparent sections to provide for visual observation. A screen to support the filter medium of paper, cloth, fibrous, or synthetic foam material will be placed between the two sections. A diagrammatic drawing of the filter appears as Figure 4. Pressure difference across the filter could be used as an indication of the filter effectiveness.

A dual filter setup is suggested so that either one can be used while the other one is being cleaned. This will allow a continuous operation.

### Measuring Devices

A visual or an instrumental examination port may be installed after the filter to check the condition of the effluent before it is discharged from the process. As there is not available at this time a reliable continuous measuring and monitoring device for oil concentration in water, any device that can act as go/no-go gage or alarm may be used.

Several investigators (5),(6),(7) have been looking into devices based on the optical principle, but no published results have been made available. Their developments are being followed. A foreign made "Oleometer" using ultrasonics to emulsify oil into particle sizes of the range 0.2 - 0.3 micron and then examine the emulsion for turbidity has been said to be able to measure oil to 100 ppm. Details of this device are being sought in regard to its operation and availability.

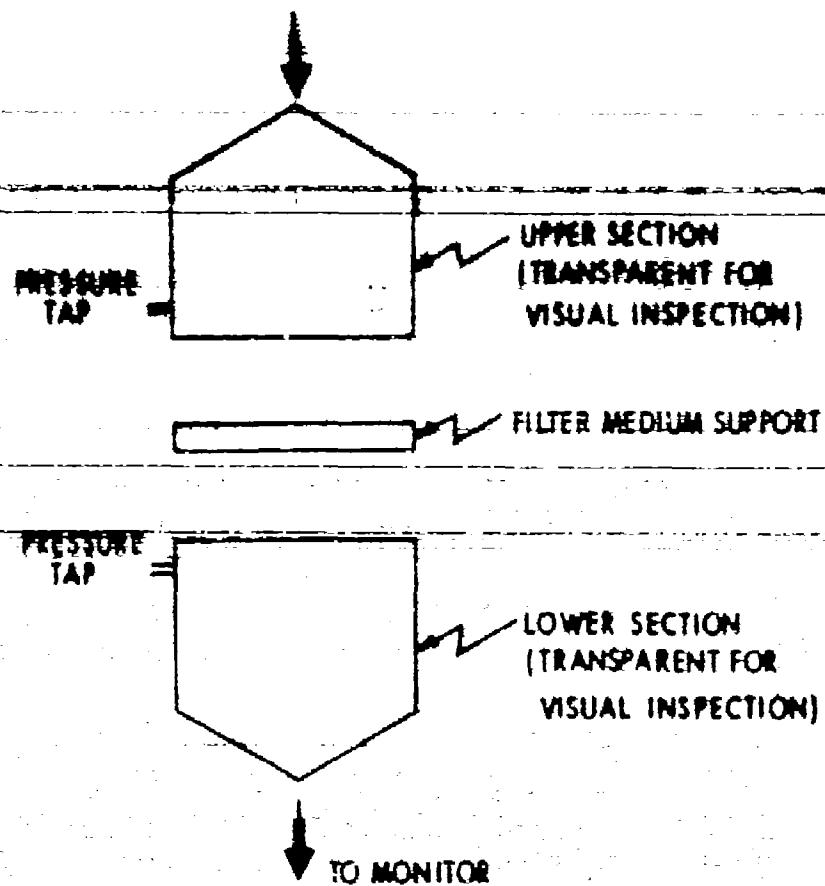


Figure 4  
Filter

While a satisfactory measuring device for effluent contamination may be difficult to procure because of the requirement of a low contamination range to be sensed, an interfacial detector to control the separation process may be more readily obtained. An alarm may be associated with the interface detecting device to warn that the oil-water interface is approaching a critical level and to interrupt the process and prevent pumping effluent overboard. Such a scheme may not be completely satisfactory if the existing or proposed low contamination limits remain as requirements. However, it should reduce the incidence of gross contamination. The availability of such devices has been determined, and some of these will be available in the laboratory experiments.

## EXPERIMENT

To test the proposed process it is planned to fabricate and/ or assemble the equipment described above. A reservoir of salt water (Severn River water) will be contained by the use of floating open-end cylinders or storage tanks. To this water various amounts of different types of oil will be added to simulate the bilge water situation. This oily water mixture will then be pumped through the separating process assembly at different rates. The amount of oil in water of both the influent and effluent streams will be determined by quantitative solvent extraction procedures. Proposed measuring devices will be incorporated and evaluated in this setup as they become available. On the basis of results obtained, modifications and improvements in the process will be made. (It is planned to use this installation to examine other oil-water separating processes as the need for them becomes apparent.)

## FUTURE ACTION

After the laboratory experiment results have been evaluated, and provided they are found satisfactory, a shipboard test will be made to establish the need for changes and improvements. Upon completion of this testing, and possible changes resulting therefrom, final plans and test procedures for construction and use of this process in the Fleet will be prepared.

## Appendix A

### Technical References

- 1 - Yu, T. S., and D. R. Ventriglio, "Shipboard Oil Pollution Control System for Ballast and Bilge Water - A State-of-the-Art Search," NAVSHIPRANLAB Annapolis Rept MATLAB 244, Sep 1969
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13. ABSTRACT

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4. Continuous Separator  
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Task 13216)

1. Bilge Water  
2. Oil Pollution Control  
3. Gravity Separator  
4. Continuous Separator  
I. Yu, Tsai Shan  
II. Title...  
III. Report 3191

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